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Energy and carbon budgeting of tillage for environmentally clean and resilient soil health of rice-maize cropping system

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ABSTRACT

Human interventions in the environment leading to higher green house gas emissions which are degrading the soil and environment quality. Traditional/conventional tillage systems following since inception and residue burning are accelerating the degradation of soil and environment leading to food insecurity. The present study was executed to evaluate energy budgeting, carbon foot prints, gaseous emission and soil health under conservation tillage with residue retention for identifying cleaner production technology in rice-maize system. The novelty of the study is that it examines the integrated effect of tillage, residue retention through mulching on GHG emission along with soil health, energy consumption and carbon footprints together as conservation effective measure for sustainable and clean agricultural production. Zero tillage reduced the energy consumption by 56% and carbon footprints by 39% and besides that N_2O emission was 20% lower than conventional tillage. Apart from clean environment, soil health was also improved by adoption of zero tillage in terms of NPK status, labile pool of carbon and enzymatic activities; the population of all the microbiota was increased, which was around 21.3, 51.2 and 27.6% higher in bacteria, fungi and actinomycetes. Crop residue retention as residue mulching (rice straw) significantly improved the crop productivity, microbial biota and enzymatic activities of soil, but it increased the energy consumption and carbon footprints by around 10%. N_2O emission was also enhanced by residue mulching, and higher the quantity of residue used as mulch, more was emission. Although in initial years some yield penalty (10–15%) was recorded but in long run zero tillage can be a step towards sustainability as it can be a valuable approach for resilient soil health and cleaner production of maize in rice–maize system.

1. Introduction

Maize is promising crops in India and world under different agro-climatic conditions and rice—maize system (RMS) has becomes a foremost option for diversification of prevailing rice-rice cropping systems and cultivated in 3.55 m ha in Asia (Timsina et al., 2011). Conventional maize planting was generally done by repetitive tillage to prepare the field and it takes around 25–30 days after kharif rice for proper field preparation. Its consequences lead to delayed sowings and the crop may get subjected to hot weather at anthesis and grain filling stage. Apart from that, rice and maize grown in a succession needs contrasting soil hydrology and conditions because anaerobic environment of transplanted rice is not appropriate for maize. The distinct growing environment and

Abbreviations: CA, Conservation agriculture; CE, Carbon efficiency; CFs, Carbon foot-prints; CFy, carbon foot-prints based on yield; CH_4, Methane; CO_2, Carbon dioxide; CSI, carbon sustainability index; CT, Conventional tillage; DAS, Days after sowing; DHA, Dehydrogenase activity; EC, Electrical conductivity; EP, Energy productivity; EUE, Energy use efficiency; FDA, Fluorescein diacetate activity; GHG, Green house gases; GWP, Global warming potential; IPCC, Intergovernmental panel on climate change; K, Potassium; MBC, Microbial biomass carbon; MBN, Microbial biomass nitrogen; N, Nitrogen; N_2O, Nitrous oxide; NE, Net energy; P, Phosphorus; PE, Energy profitability; PSOC, Permanganate oxidizable carbon; RDF, Recommended dose of fertilizer; RM3, Residue mulching at the rate of 3tonnes per hectare; RM6, Residue mulching at the rate of 6tonnes per hectare; RMC, Readily mineralizable carbon; RMS, Rice-maize system; SE, Specific energy; SOC, Soil organic carbon; TOC, Total organic carbon; WR, Without residues; WSC, Water soluble carbon; ZT, Zero tillage; @, at the rate of.

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related intercultural operations leads to several transformations in soils either physical or chemical, which may decline fertility. Globally, deterioration in soil health is may be the key constraint contributing to poor yields in subsistence agriculture, and thus a major contributor to food insecurity (Lal, 2004). Now a days, degradation in fertility and productivity of agricultural soils was attributed to the following of inappropriate tillage practices, which questions the sustainability of crop production especially tillage intensive crops like maize. Use of heavy machineries under mechanized cultivation requires greater energy and carbon input for better output in per unit area, which lead to higher energy consumption, cost and deterioration in soil health, this situations alarms for search of alternative methods of tillage for higher energy and carbon use efficiency with considerable productivity. Several crops including maize can be successfully cultivated without primary tillage under zero tillage, with least cost of cultivation, also with less energy and carbon consumption.

Conservation agriculture (CA) is a conception with increasing adoption globally owing to its potential for conserving soil health and better crop productivity. Minimum tillage with soil cover has been reported to decrease runoff and soil erosion, and to enhance the soil moisture, and soil organic matter accumulation (Palm et al., 2014). Among the cultivation practices, land preparation alone contributes around 25–30% cost which can be reduced by adopting conservation tillage and it may be associated with lower energy and carbon inputs as compared to conventional practices (Uri, 2000). Crop residues are the main resource of organic carbon supply in the rice-based cropping systems and are repeatedly accredited to raise in soil organic carbon (SOC), and water retention (Singh et al., 2005). Experimental facts recommend that CA based modified tillage and crop production systems can produce both immediate and long-term benefits like improved soil quality.

Crop production includes several operations like tillage, manuring and fertilization, irrigation which are leading to emission of GHGs with strong adverse effects on the environment. The burning of fossil fuel for energy during agricultural production is a major contributor to the emission of GHGs (Tjandra et al., 2016). Therefore, quantification and assessment of the carbon foot-prints and energy consumption in RMS, could address the related environmental issues. For policy makers, such assessment can also improve the awareness about the environment, climate change and may facilitate the decision-making process for promotion of environment friendly technologies (Xue et al., 2016). Several agricultural operations including ploughing of soil might be resulted in increase in the concentration of greenhouse gases (GHGs) namely CO_2, CH_4 and N_2O. Although CO_2 is the most copious gas, N_2O and CH_4 are also vital because of their global warming potentials (GWPs) of 265 and 28 times that of CO_2, respectively might be due to their distinctive radiative nature and long residence period in the atmosphere (IPCC, 2013). Agricultural practices like nitrogenous fertilizer application, tillage system followed, manuring, and residue burning influences the N_2O emission from cultivated soils (Dalal et al., 2003). Conservation tillage is also helpful for sequestration of carbon in soils to mitigate the atmospheric abundance of CO_2 (Denef et al., 2004). Previous studies on N_2O emission under no/zero and minimum tillage has generated mixed results. Six et al. (2004) reported that N_2O emission were higher under no-till soil during the initial10 years, but after that, emissions were lower than conventional tillage in humid ecosystems. Mixed reports are available for N_2O emissions under no tillage, according to some researchers emission was higher (Ball et al., 1999; Baggs et al., 2003) and some found no difference. In the light of given facts, it is the need of time to compare the different tillage systems for their benefits in terms of reducing energy consumption, gaseous emission and carbon inputs for sustainable production.

Zero tillage is widely recommended for crop production globally to improve soil health and enhance soil carbon and organic matter as compared to CT. However, the effect of ZT on climate change mitigation has been intensively debated because of the significant unpredictability in individual field experiments (Powlson et al., 2014; Neufeldt et al., 2015; Abdalla et al., 2016). Previous studies have demonstrated that ZT significantly reduced (Harada et al., 2007), increased (Zhang et al., 2015) or did not affect (Bayer et al., 2015) gaseous emission. In addition, the effects of ZT on CH_4 and N_2O emissions were often inconsistent like a study reported that ZT reduced CH_4 but increased N_2O emission in paddy field compared with CT (Ahmad et al., 2009). The trade-off relationship may counteract the effect of ZT on GHG emission and mitigation. The highly diverse results from individual studies are unlikely to reveal a general pattern of soil tillage on GHG emission. Although some studies have been conducted to compare the effect of ZT and CT on gaseous emissions (Van Kessel et al., 2013; S.C. Zhao et al., 2016) but the integrated effects of tillage on soil health, soil properties, soil microbiota, energy consumption and carbon footprints along with GHG emission has not been well documented.

Keeping the above facts in mind the study was conducted in an experiment continuing for last 3 years as rice-maize system, with the hypothesis that practicing zero tillage might be resulted in reduced N_2O emission from agricultural soils which may be a mitigating factor in the climate changing scenario. Therefore, the study is conducted with the objectives (1) to determine the effect of tillage, residue mulching and N management on N_2O flux, dynamics of available NPK and carbon fractions, (2) to assess the benefits of conservation tillage on energy budgeting, carbon foot prints and carbon use efficiency, (3) to evaluate the microbial status and soil enzymatic activities under different tillage and residue mulching with different levels on N application to find out whether the system is productive, healthier, cleaner and sustainable or not. In the RMS, rice alone is responsible for >10% of global agricultural greenhouse gas (GHG) emissions and about 1.3%–1.8% of the anthropogenic GHG emissions (Maraseni et al., 2018), but GHG emission in rice were thoroughly studied at National and global level. At the site of the study, Bhattacharyya et al. (2013) extensively studied it in rice-rice at Cuttack, India and results suggested that in anaerobic condition of rice N_2O emission is less but when soil turned aerobic for maize cultivation, N_2O emission is more, therefore, in this study, we have evaluated N_2O emission in maize only. The study is novel in its way as it examines the integrated effect of tillage, residue incorporation through mulching in RMS on GHG emission along with soil health, soil properties, soil microbiota, energy consumption and carbon footprints together as conservation effective measure for sustainable and clean agricultural production practice over conventional technologies which are responsible for high GHGs emission, energy consumption and adverse effect on soil health. Small investments in the form of these technologies can be easily adaptable to the farmers especially small and marginal farmers having low resources and adaptation capacities.

2. Materials and methods

2.1. Site description

Nitrous oxide fluxes and soil chemical and biological properties were measured in the conservation tillage experiments that were conducted at ICAR-National Rice Research Institute, Cuttack, Odisha, India during the Rabi season of 2015–16. The experimental site is situated at longitude and latitude of 20°26′57.84″N, 85°56′3.41″E and 24 m above mean sea level. The site falls under sub-moist tropical atmosphere with short winter and long sweltering

summer period and substantial cyclonic precipitation amid storm season. The temperature of the site is 31.6 (maximum) and 22.1 °C (minimum) during the growing period and annual rainfall is 150 cm. The soil is classified as Aeric Endoaquept with sandy clay loam texture (30.9% clay, 16.6% silt, 52.5% sand), bulk density 1.40 Mg m^{-3}, pH- 6.5, electrical conductivity 0.5 dS m^{-1}, total C 0.78%, and total N 0.08%.

2.2. Design of experiment

The statistical design used for layout of experiment was split split-plot design and treatments (plot size of 30 m^2) were replicated thrice. In the main plots, maize (variety- Super Maize Hybrid 36) was grown under the two different tillage systems viz., conventional tillage (the combined primary and secondary tillage operations including 3–4 ploughings normally performed in preparing a seed-bed) and zero tillage (tillage operations are restricted to sowing the seeds in row zone only). Sub plots comprised of residue incorporation, (residue of rice crop was applied to maize crop as mulch), i.e. without residue (WR), residue mulching @ 3 t ha^{-1} (RM_3) and residue mulching @ 6 t ha^{-1} (RM_6). 75% N ($N_{75\%}$) and 100% N ($N_{100\%}$) application of recommended dose (RDF) (80:40:40 kg NPK ha^{-1}) were kept in sub sub-plots, this factor was applied to rice crop only, to see the effect of residue incorporation and fertilization of Rabi season crop is having any carry over effect to rice. In wet season rice crop (variety- Naveen) was sown with dry direct seeding method in the first fortnight of June. Maize was sown after 15 days of rice harvesting, in ZT, holes were made and seed was sown manually, whereas in CT, field was prepared with power tiller, then leveling followed by sowing. Rice residue was applied as mulch 7DAS, when seed starts germinating, as per the treatments. In ZT treatments, Paraquat was sprayed to control the rice ratoons. In CT ridges were made around maize plants after 25 days of sowing. Crop was fertilized as per the recommended package of practices and irrigated as per its requirement, during early stages on 10–12 days interval and later at weekly interval.

2.3. Soil sampling

Soil sampling was done with sample probe auger at the depth of 0–15 and 15–30 cm. After mixing the subsamples, a composite soil samples were prepared for the analysis. Fresh soil samples were used for microbial and enzymatic analysis (stored in refrigerator) and dried samples were used for analyses of available N, P, K and soil C fractions. The analysis procedures for available N, P, K and soil C fractions, soil enzymatic activities and microbial populations were presented as Table 1.

2.4. Nitrous oxide flux measurement

Nitrous oxide (N_2O) flux was monitored using the manual closed chamber method throughout the year in rice. The gas samplings were done after 10 days of sowing the maize crop at 7 days intervals in the dry season. For measuring N_2O flux sampling was done from all the treatments in each replication in the morning around 09:00–09:30 a.m. and in the afternoon at 3.00–3.30 p.m., and the average was considered as estimation of flux for the day. For measuring N_2O emissions, fabricated Perspex chamber (53 cm length x 37 cm width x 51 cm height) were placed between two rows of maize. For determining N_2O emissions procedure of Bhattacharyya et al. (2013) was followed and for calculating the N_2O flux linear interpolation was used as suggested by Datta et al. (2009).

2.5. Energy budgeting

Energy budgeting of a cropping system includes the input energy consumed in various operation and farm inputs and output energy produced in terms of grain and stover/straw yield. For calculating input energy consumption the input data on fertilizers, seeds, plant protection chemicals, fuels, human labor, machinery power, and field operations were used (Table 2) and multiplied to their respective energy conversion coefficients (Table 3). To check the energy efficiency of the system various parameters were used and calculated (Chaudhary et al., 2017) as follows:

$$Net\ energy\ (NE) = Output\ energy - input\ energy$$

$$Energy\ use\ efficiency\ (EUE) = Output\ energy\ \left(MJ\ ha^{-1}\right) \times \Big/ input\ energy\ \left(MJ\ ha^{-1}\right)$$

$$Energy\ productivity\ (EP) = Crop\ economic\ yield\ \left(kg\ ha^{-1}\right) \times \Big/ input\ energy\ \left(MJ\ ha^{-1}\right)$$

$$Specific\ energy\ (SE) = input\ energy\ \left(MJ\ ha^{-1}\right)\Big) \times /system\ productivity\ \left(kg\ ha^{-1}\right)$$

$$Energy\ profitability\ (PE) = Net\ energy\ return\ \left(MJ\ ha^{-1}\right) \times \Big/ input\ energy\ \left(MJ\ ha^{-1}\right)$$

2.6. Carbon budgeting

Emission factors (Table 4) were used to calculate carbon footprints (CFs) of various inputs and equivalent carbon emissions (Table 5) were used for calculating carbon equivalent per hectare (Ce ha^{-1}) of input and output (Pandey and Agrawal, 2014). Summation of all the inputs and outputs were represented as total carbon input and output.

$$CFy = {}^{CFs}/_{System\ productivity}$$

$$Carbon\ efficicieny = {}^{Carbon\ output}/_{carbon\ input}$$

$$carbon\ sustainability\ index\ (CSI) = \frac{Carbon\ output - carbon\ input}{carbon\ input}$$

2.7. Statistical analysis

The data for all the parameters were analyzed by using analysis of variance (ANOVA) of a split split-plot design to examine the main and interactive effects of multiple factors in SAS version 9.3. Repeated-measures of ANOVA were used to test the treatment significance, and their interactive effects on soil N_2O emission, carbon fractions, yields, enzymatic and microbial properties of maize. Multiple comparisons (Least Significant Difference) were conducted if significant effects of treatment set at an alpha level of

Table 1
Methods followed for the analysis of different soil quality parameters.

S. No.	Parameter	Method followed	Reference
1.	Available nitrogen	Alkaline $KMnO_4$ method	Subbiah and Asija (1956)
2.	Available phosphorus	Bray's extractant method	Dickman and Bray (1940)
3.	Available potassium	Ammonium acetate extractant method	Hanway and Heidel (1952)
4.	Microbial biomass carbon (MBC)	Modified chloroform fumigation–extraction method	Witt et al. (2000)
5.	Microbial biomass nitrogen (MBN)	Fumigation–extraction method	Brookes et al. (1985)
6.	Readily mineralizable carbon (RMC)	Extraction with 0.5 M K_2SO_4 and wet digestion with dichromate	Inubushi et al. (1991) and Vance et al. (1987)
7.	Water soluble carbohydrate carbon (WSC)		Haynes and Swift (1990)
8.	Permanganate oxidizable carbon (PSOC)		Blair et al. (1995)
9.	Fluorescein diacetate activity (FDA)		Adam and Duncan (2001)
10.	Dehydrogenase activity (DHA)	Reduction of 2,3,5-triphenyltetrazolium chloride (TTC)	Casida et al. (1964)
11.	β-glucosidase (BGLU) acctivity		Eivazi and Tabatabai (1988)
12.	Urease activity		Tabatabai and Bremner (1972)
13.	Acid and alkaline phosphatase activity	P-nitrophenyl phosphate disodium (pnpp, 0.15 M)	Tabatabai and Bremner (1969)
14.	Total bacterial, fungal and actinomycetes populations	Spread plate technique	
15.	Culturable NH_4^+ and NO_2^- oxidizing atutotrophs (AMOOX and NITROX, respectively)	MPN method	Schmidt and Belser (1982))
16.	Denitrifying bacteria population		Abd-el-Malek et al., (1974)

Table 2
Input requirements of the individual crops grown during the field experiment.

	ZT						CT					
	WR		RM_3		RM_6		WR		RM_3		RM_6	
	$N_{75\%}$	$N_{100\%}$	$N_{75\%}$	$N_{100\%}$	$N_{75\%}$	$N_{100\%}$	$N_{75\%}$	$N_{100\%}$	$N_{75\%}$	$N_{100\%}$	$N_{75\%}$	$N_{100\%}$
Fertilizer (kg ha^{-1})												
N	140	160	140	160	140	160	140	160	140	160	140	160
P_2O_5	70	80	70	80	70	80	70	80	70	80	70	80
K_2O	70	80	70	80	70	80	70	80	70	80	70	80
Seed (kg ha^{-1})												
Rice	60	60	60	60	60	60	60	60	60	60	60	60
Maize	15	15	15	15	15	15	15	15	15	15	15	15
Plant protection chemicals (kg ha^{-1})												
Fungicide	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Herbicide	7.8	7.8	8	8	8.5	8.5	2	2	2.5	2.5	2.9	2.9
Insecticide	2	2	2	2	2	2	2	2	2	2	2	2
Irrigation(mm ha^{-1})	180	180	160	160	120	120	240	240	210	210	200	200
Diesel (L ha^{-1})	25	25	28	28	28	28	122	122	125	126	126	126
Machinery (hr ha^{-1})	10	12	12	12	13	13	26	26	29	29	31	31
Labour (8-hr day^{-1} ha^{-1})												
Men	92	92	94	94	94	94	101	101	99	99	96	97
Women	129	129	136	137	127	137	161	161	149	149	147	146

ZT, Zero tillage; CT, Conventional tillage; WR, Without residues; RM3, Residue mulching at the rate of 3 tonnes per hectare; RM6, Residue mulching at the rate of 6 tonnes per hectare.

0.05 were found. Two-way ANOVA with LSD test were performed for yield and other soil parameters to find out treatment significance and their interaction. The relationship among carbon and nitrogen fractions, soil enzymes, yield and N_2O flux was determined through correlation and regression analysis in SAS version 9.3.

3. Results

3.1. Rice and maize yield

The tillage practices and residue mulching had significant effect on seed yields of rice and maize and system productivity as well (Table 6). The yield of both the crops was significantly higher in CT, which was around 10.6 and 13.4% more in rice and maize respectively, as compared to ZT. Residue mulching at different rates had different effects on rice and maize yield, although residue mulching was done in maize but it had significant effect on rice yield also. Rice yield under ZT was highest (2.7%) when residue was not applied and minimum when 6 t residues was applied, whereas, in CT, yield was highest (10.4%) with RM3 mulching. However, in maize, significantly lowest yield (7.9%) was obtained with no residue application, in ZT yield was highest under RM3 (8.2%) and in CT it was in RM6 (5.5%). application of N at higher rates performed better and produced higher yield in both crops. total yield of R-M system was the summation of rice and rice equivalent yield of maize and it follows the trend as of both the crops. Highest system yield was obtained under CT, with RM6 and 100% N application.

3.2. Energy budgeting

The total energy requirement of the system was varied significantly under zero and conventional tillage and with the application of residue mulch and nitrogen (Table 7). The total energy requirement was higher in conventional tillage (25412 MJ ha^{-1}) than ZT and energy requirement increased with the increasing quantity of mulch. Among the all the inputs fertilizer consumed highest energy followed by diesel in CT and labour in ZT (Fig. 1). Among the tillage

Table 3
Energy equivalents of inputs and outputs in agricultural production.

Particulars	Unit	Energy equivalent (MJ unit^{-1})
Inputs		
Human labour		
Adult man	hr	1.96
Women	hr	1.57
Diesel	L	56.31
Farm machinery	kg	62.7
Chemical fertilizers		
N	kg	60.6
P_2O_5	kg	11.1
K_2O	kg	6.7
Irrigation water	m^3	1.02
Pesticides	kg	120
Seed		
Rice	kg	14.7
Maize	kg	16.6
Outputs		
Rice	kg	14.7
Maize	kg	16.6
Rice Straw	kg	13.4
Maize stover	kg	18.0

Table 4
Emission factors of agriculture inputs used in the estimation.

Particulars	Unit	Kg CO_2eunit^{-1})	References
Human labour	Day	0.86	Deng (1982)
Diesel	L	3.32	Deng (1982)
Farm machinery	Hr	3.32	Deng (1982)
Chemical fertilizers			
N	kg	4.96	Lal (2004)
P_2O_5	kg	1.35	Lal (2004)
K_2O	kg	0.58	Lal (2004)
Seeds	kg	1.22	Wang et al. (2015)
Pesticides			
Fungicide	L	3.9	Lal (2004)
Herbicide	L	6.3	Lal (2004)
Insecticide	L	5.1	Lal (2004)

Table 5
Estimates of equivalent carbon emissions for agriculture inputs used in the experiment.

Equivalent carbon emission	Unit	Equivalent carbon emission	References
Diesel	kg	0.94	Lal (2004)
MB ploughing	kg	15.4	Lal (2004)
Field cultivation	kg	4.1	Lal (2004)
Irrigation	kg	9.4	Lal (2004)
Sowing/planting	kg	3.2	Lal (2004)
No-till planting	kg	3.8	Lal (2004)
N	kg	1.3	Lal (2004)
P	kg	0.2	Lal (2004)
K	kg	0.15	Lal (2004)
Fungicide	kg a.i.	3.9	Lal (2004)
Herbicide	kg a.i.	1.5	Lal (2004)
Insecticide	kg a.i.	5.1	Lal (2004)

systems zero tillage saved considerable energy over CT, especially in machinery and diesel use leading to around 56% total energy saving (Fig. 1). Residue mulching increased the energy consumption in both the tillage systems, the consumption is around >1.5% higher with residue mulching over no residue application. Apart from output energy, there are several other parameters for judging the energy efficiency like NE, EUE, SE, EP and PE. Like energy consumption output energy was higher in CT than ZT, but output and net energy is highest in RM3 in both the tillage systems as compared to highest input energy with RM6. Energy use efficiency

Table 6
Seed yield of rice, maize and system productivity, N_2O emission and its CO_2 equivalent in maize after a 3-yr conservation agriculture experiment, of rice maize cropping system. P values are indicated for analysis of variance of tillage, residue mulch and N application.

			Seed yield (t ha^{-1})			N_2O kg ha^{-1}	CO_2 eq
			Rice	Maize	R-M system		
ZT	WR	$N_{75\%}$	4.87	7.23	11.58	0.61	182.8
		$N_{100\%}$	4.98	7.32	11.78	0.69	206.6
	RM3	$N_{75\%}$	4.82	8.02	11.87	0.88	261.2
		$N_{100\%}$	4.93	8.10	12.11	1.00	299.0
	RM6	$N_{75\%}$	4.73	7.59	12.18	1.16	346.7
		$N_{100\%}$	4.83	7.73	12.35	1.25	371.5
CT	WR	$N_{75\%}$	5.03	8.19	12.64	0.80	237.4
		$N_{100\%}$	5.12	8.32	12.85	0.90	268.2
	RM3	$N_{75\%}$	5.58	8.77	13.72	1.11	329.8
		$N_{100\%}$	5.90	8.85	14.12	1.15	341.7
	RM6	$N_{75\%}$	5.25	8.95	13.56	1.35	403.3
		$N_{100\%}$	5.43	9.06	13.84	1.44	428.1
$LSD_{P=0.05}$			**0.481**	**0.764**	**1.073**	**0.024**	**11.63**
Tillage systems (T)			**	***	**	**	**
Residue Incorporation(R)			*	***	**	**	**
Nitrogen Application (N)			**	**	**	*	*
TxR $LSD_{P=0.05}$			*	**	**	*	*
TxN $LSD_{P=0.05}$			ns	**	*	*	*
RxN $LSD_{P=0.05}$			*	*	*	*	*
TxRxN $LSD_{P=0.05}$			ns	**	*	*	*

ZT, Zero tillage; CT, Conventional tillage; WR, Without residues; RM3, Residue mulching at the rate of 3 tonnes per hectare; RM6, Residue mulching at the rate of 6 tonnes per hectare.

and energy productivity was significantly higher under ZT than CT, and reverse was the case with SE and PE. By adopting zero tillage instead of CT, EUE can be increased by 19.2% and EP can be enhanced upto 18.1% (Table 8). Residue mulching resulted in the higher output energy leading to more NE, EUE, EP and PE as compared to no residue incorporation.

3.3. N_2O emission

Soil N_2O emission was significantly influenced by residues mulching and tillage systems, the N_2O flux ranged from 3.23 to 114 and 3.8–133 μg N_2O m^{-2} h^{-1} in ZT and CT, respectively (Fig. 2). Daily N_2O flux rates were significantly higher (20.7%) under CT than that of ZT irrespective of residue and N application. Within the experimental period, highest N_2O emission from soil occurred in the residue mulching, which was around 49.8 and 65.3% higher in CT and ZT respectively as compared to no residue application (Fig. 3). Higher the amount used for residue mulching, more was the N_2O emission from soil. Similarly, N application contributed to higher N_2O emission, 100% N application resulted in 7.5 and 9.8% higher emission in CT and ZT, respectively over 75% N application (Fig. 2).

Overall all the treatments caused net release of N_2O; the annual N_2O flux was significantly higher from CT (20.4%) than ZT tillage. Residue mulching significantly increased the annual N_2O flux, around 64.6 and 48.2% higher N_2O released from soil when mulching was done with residue as compared to no residue application (Table 2). Application of higher N resulted in 6.4 and 11.4% annual N_2O release from CT and ZT, respectively, irrespective of the residue mulching. as per the interaction of treatments was concerned, maximum annual N_2O released under CT with RM6 and 100% N application (Table 6).

Table 7
Energy input in a 3-yr conservation agriculture experiment of rice maize cropping system influenced by tillage, residue mulch and N application.

			Energy input (MJ ha^{-1})						
			Labour	Machinery	Diesel	Fertilizer	Seed	Pesticides	Total
ZT	WR	$N_{75\%}$	3063	627	1408	9730	1131	1356	17315
		$N_{100\%}$	3063	752	1408	11120	1131	1356	18830
	RM_3	$N_{75\%}$	3182	752	1577	9730	1131	1380	17752
		$N_{100\%}$	3195	752	1577	11120	1131	1380	19155
	RM_6	$N_{75\%}$	3069	815	1577	9730	1131	1440	17762
		$N_{100\%}$	3195	815	1577	11120	1131	1440	19277
CT	WR	$N_{75\%}$	3606	1630	6870	9730	1131	660	23627
		$N_{100\%}$	3606	1630	6870	11120	1131	660	25017
	RM_3	$N_{75\%}$	3424	1818	7039	9730	1131	720	23862
		$N_{100\%}$	3424	1818	7095	11120	1131	720	25308
	RM_6	$N_{75\%}$	3352	1944	7095	9730	1131	768	24019
		$N_{100\%}$	3355	1944	7095	11120	1131	768	25412

ZT, Zero tillage; CT, Conventional tillage; WR, Without residues; RM3, Residue mulching at the rate of 3 tonnes per hectare; RM6, Residue mulching at the rate of 6 tonnes per hectare.

3.4. Carbon footprints (CFs) and use efficiency

Carbon footprints, input and output was assessed from the different tillage systems in order to compare their performance in GHG emission. N_2O emission was measured directly and carbon footprints were calculated by multiplying different inputs to their emission equivalents. Carbon footprints recorded higher under CT in all the inputs except pesticides, which was higher in ZT (Table 9). Among various inputs included in the cultivation, CFs were highest for fertilizer application followed by N_2O emission from farm under ZT and diesel in CT (Fig. 4). Under CT, diesel use was the second most important contributor to CFs but the values changed by adopting ZT. Following of ZT reduced the CFs by about 293 and 11% in diesel and labour, respectively, leading to 39% total reduction as compared to CT (Fig. 4). Apart from tillage methods, residue mulching and higher N application to rice also increased CO_2-e emissions, in totality RM6 and RM3 led to 10.5 and 5.8% higher CO_2-e emissions as compared to no residue mulch, similarly, $N_{100\%}$ resulted in 8.3% higher emission over $N_{75\%}$ application. CF in respect to yield (CFy) also followed the similar trend that is CT and residue mulching resulted in higher CFy, on an average ZT recorded 25.6% lower CFy over CT (Table 9).

Tillage system and residue also significantly influenced the carbon input, output, efficiency and sustainability (Table 10). By adopting ZT carbon input was reduced so as output, but carbon efficiency and sustainability was increased by 6.9 and 7.9% respectively as compared to CT. Carbon budgeting was varied differently with residue mulching, that is low quantity of residue (RM3) increased the carbon efficiency and sustainability upto 5.5 and 6.2% but higher quantity of residue (RM6) did not further increased the efficiency and decreased the sustainability.

3.5. Soil chemical properties

Among the soil chemical properties soil pH and EC was not affected by tillage, residue, N application and their interaction was also non-significant (Table 11). However, status of available NPK was significantly improved with the residue mulching, higher N application. Available NPK content was around 14.1, 17.0 and 16.2% higher, respectively under ZT as compared to CT. Residue mulching @ 6 t ha^{-1} recorded highest values of NPK content, which was 13.3 and 37.1% higher over RM3 and no residue application, respectively. N application @ 100% of RDF not only improved N content (5.8%) in soil but also improved P (6.3%) and K (8.1%) contents significantly. The interaction of tillage, residue and N was also found significant in improving soil fertility status (Table 11).

3.6. Soil carbon fractions

Tillage and residue mulching followed as conservation agriculture treatments had significant ($P < 0.05$) effect on TOC and all the fractions of carbon of soil (Table 12). Values of all the carbon fractions were significantly higher under the zero tillage (ZT) and residue mulching. WSC, RMC and MBC were around 13.9, 10.6 and 14.6% higher, respectively under ZT. Residue mulching significantly improved the carbon pool of soil and results were better when residue was applied @ 6 t ha^{-1}. On an average, residue mulching resulted in 14.5, 19.7, 28.8, 39.1 and 32.8% higher TOC, POSC, WSC, RMC and MBC, respectively, over no residue application (Table 12). Nitrogen application @ 100% of RDF significantly increased the labile carbon pool of soil irrespective of tillage, but effect was more prominent under zero tillage.

3.7. Soil microbial properties

The difference in counts of soil microflora as colonies forming units (CFU) was significant among tillage system and residue mulching (Table 13). Unlike the effect on other factors CFU of various microfloras were more influenced by residue mulching than that of tillage practice. The highest counts of all the microbiota was found in ZT, which was around 21.3, 51.2 and 27.6% higher in bacteria, fungi and actinomycetes, respectively over CT. Increases in the counts of bacteria, fungi, Denitrifier and Oxidizer with RM6 were in the order of 98, 119, 37 and 52% as compared to no residue mulching. On an average, CFU count of all the microbiota was 24.9 and 69.4% higher with RM6 over RM3 and no mulching, respectively. Nitrogen application also affected the count of CFU of bacteria, fungi and actinomycetes, the counts were significantly higher under more N applied treatments.

3.8. Soil enzymatic activities

Enzymatic activities (DHA, FDA, Urease, Phosphatase, and β-glucosidase) were significantly affected by residue mulching and the tillage system employed (Table 14). N application treatments failed to impose significant effect on soil enzymes, and microbial biomass N was also remained unaffected with all the treatments. It can be easily observed that protective tillage treatment i.e. ZT, resulted in significantly higher values of enzyme activity and the maximum difference was observed in DHA (32.6% higher in ZT)

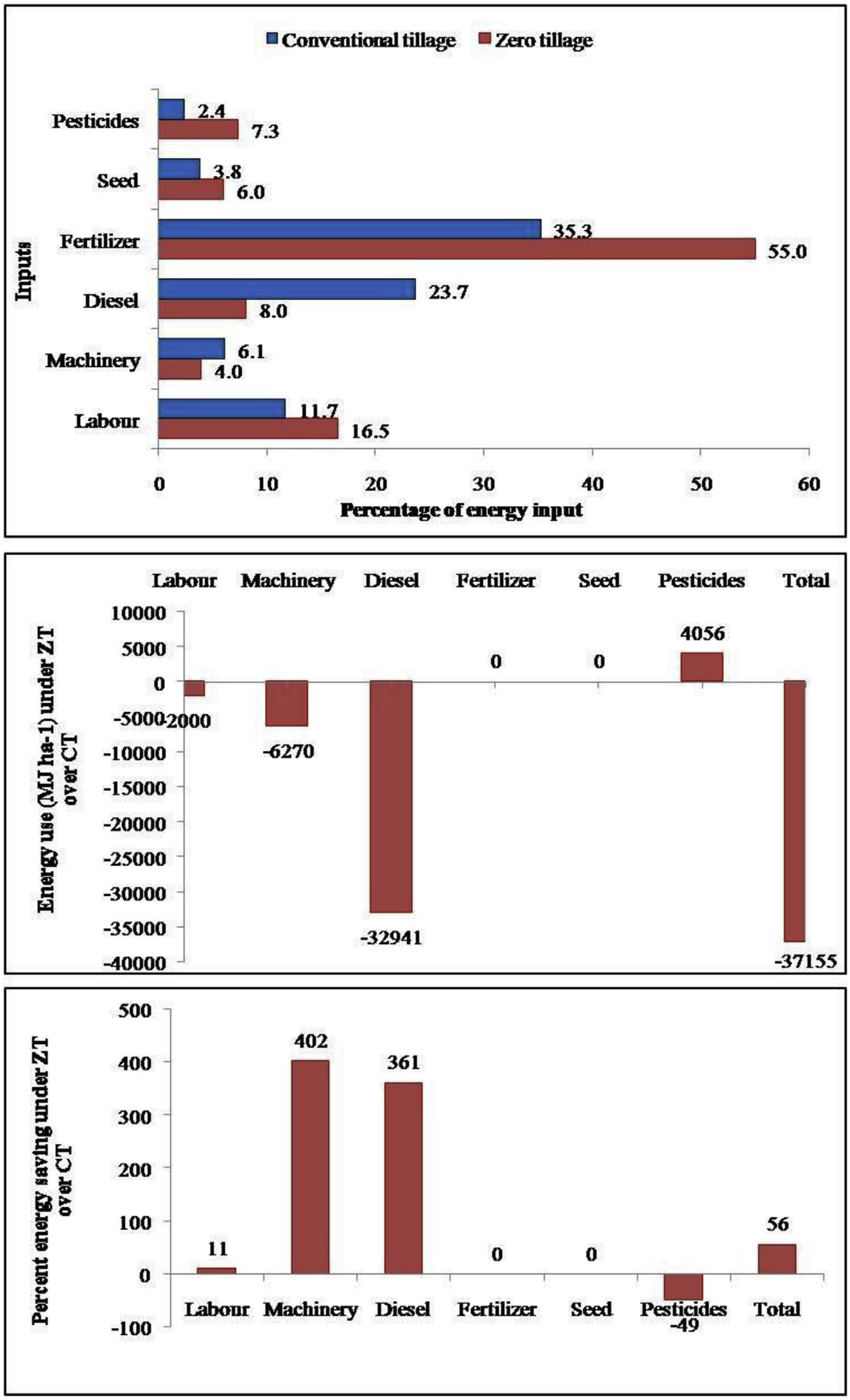

Fig. 1. Energy use pattern and energy saving under zero tillage over conventional tillage influenced by residue mulch and N application.

followed by β-glucosidase (19.3%) and in other enzymes difference between ZT and CT ranged from 7 to 9%. The soil enzymatic activities were more influenced with residue mulching than that of tillage system, here the difference ranged between 15 and 70%. Application of residue mulch (6 t ha^{-1}) significantly improved the enzyme activity, with greatest effect in DHA (72.1%) and least in Phosphatase (16.7%, both Acid and Alkaline).

4. Discussion

4.1. Impact of tillage and residue mulch on energy budgeting, gas emission and carbon foot prints

Tillage operations considerably influences the energy consumption and production, carbon foot prints and carbon use

Table 8
Energy input-output relationship in a 3-yr conservation agriculture experiment of rice maize cropping system influenced by tillage, residue mulch and N application.

	System productivity w.r.t. energy	Input energy (MJ ha^{-1})	Output energy (MJ ha^{-1})	Net energy (MJ ha^{-1})	Energy use efficiency	Energy productivity (kg MJ^{-1})	Specific energy (MJ kg^{-1})	Energy profitability (MJ ha^{-1})
ZT WR $N_{75\%}$	6.69	17315	177870	160555	10.27	0.67	1.50	58.1
$N_{100\%}$	6.26	18830	180810	161980	9.60	0.63	1.60	59.0
RM_3 $N_{75\%}$	6.69	17752	188748	170996	10.63	0.67	1.50	59.3
$N_{100\%}$	6.32	19155	191541	172386	10.00	0.63	1.58	60.0
RM_6 $N_{75\%}$	6.86	17762	181104	163342	10.20	0.69	1.46	59.0
$N_{100\%}$	6.41	19277	184632	165355	9.58	0.64	1.56	57.8
CT WR $N_{75\%}$	5.35	23627	194334	170707	8.23	0.53	1.87	53.9
$N_{100\%}$	5.14	25017	197568	172551	7.90	0.51	1.95	54.8
RM_3 $N_{75\%}$	5.75	23862	210945	187083	8.84	0.57	1.74	61.6
$N_{100\%}$	5.58	25308	216825	191517	8.57	0.56	1.79	63.3
RM_6 $N_{75\%}$	5.65	24019	208740	184721	8.69	0.56	1.77	62.3
$N_{100\%}$	5.45	25412	213003	187591	8.38	0.54	1.84	63.5
$LSD_{P=0.05}$	0.51	687	2365	1437	0.42	0.04	0.09	1.71

ZT, Zero tillage; CT, Conventional tillage; WR, Without residues; RM3, Residue mulching at the rate of 3 tonnes per hectare; RM6, Residue mulching at the rate of 6 tonnes per hectare.

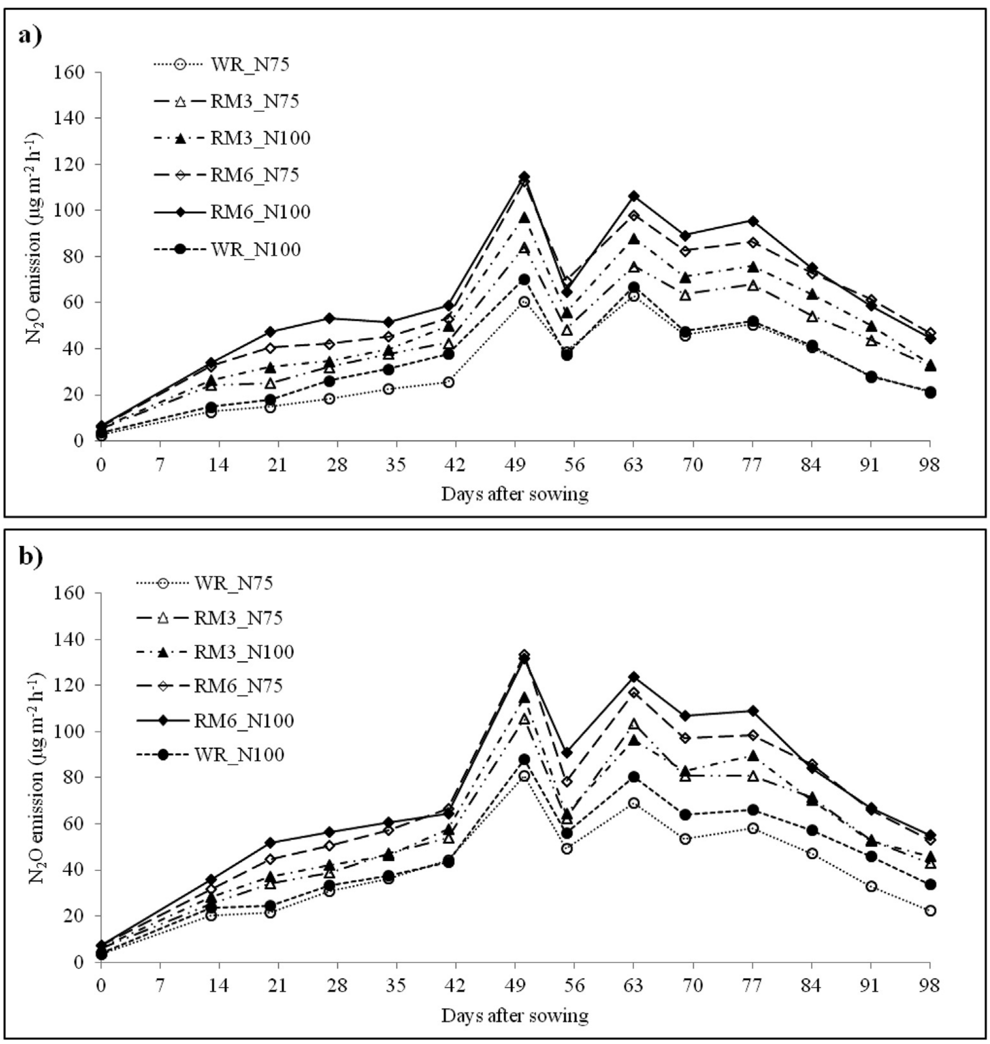

Fig. 2. N_2O emissions observed in maize grown under (a) the zero tillage and (b) the conventional tillage treatments sampled at periodical intervals during crop growth period. WR: no residue RM3: residue mulching @3 t ha^{-1}, RM6: residue mulching @5 t ha^{-1}, N75 and N100: 75% and 100% N application to preceding rice crop.

efficiency, soil health and grain yield, and the effect depends on the management practice followed. Zero-till or no-till systems that maintain surface soil coverage, led to considerable change in soil health, especially in the upper soil layers (Anikwe and Ubochi, 2007). Van Kessel et al. (2013) reported that dry climatic conditions were favorable for ZT to reduce N_2O emission based on a global meta-analysis of ZT on N_2O emission under aerobic conditions. This three-year old conservation agriculture study provides

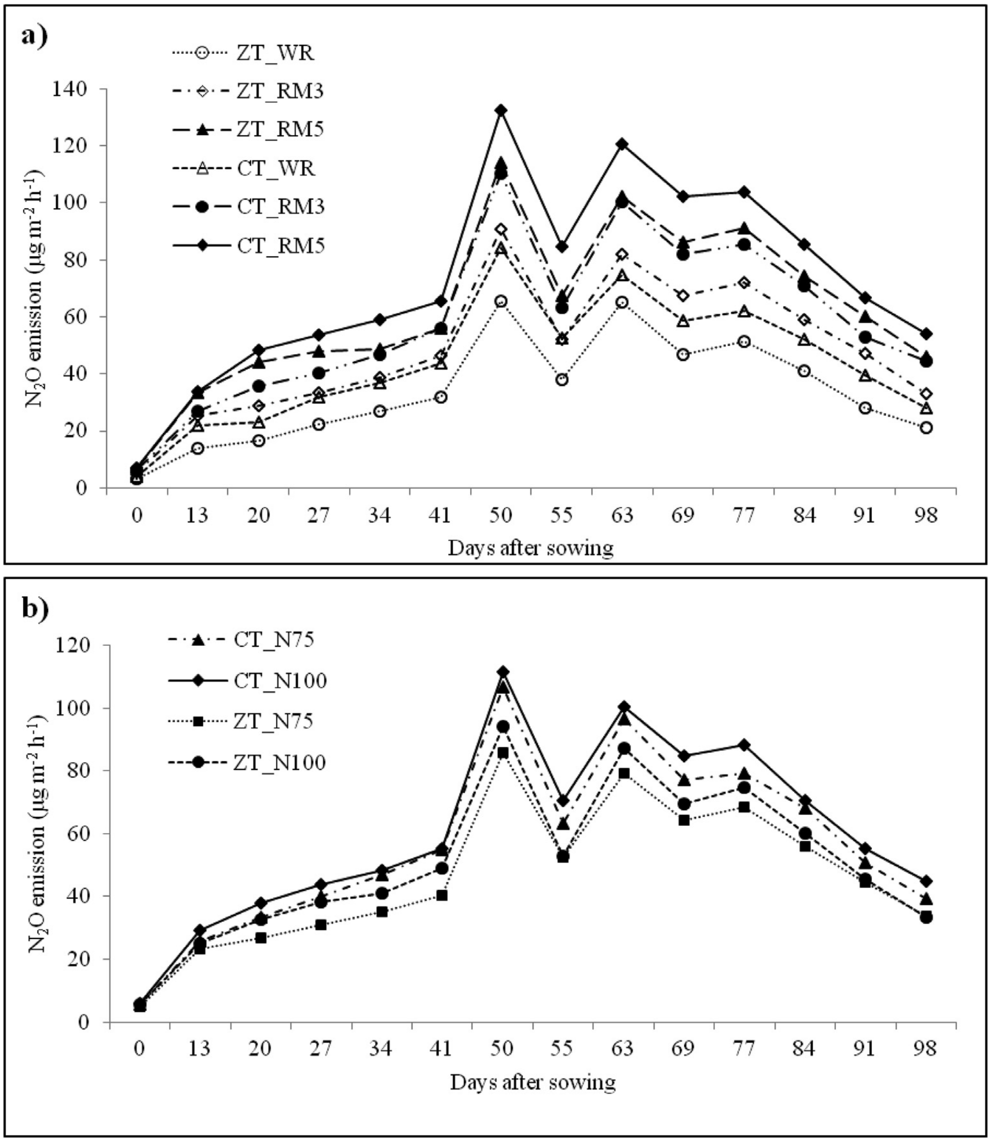

Fig. 3. N_2O emissions observed in maize grown under the zero and conventional tillage as influenced due to (a) residue mulching and (b) N application to preceding rice crop, sampled at periodical intervals. ZT: zero tillage, CT: conventional tillage, WR: no residue RM3: residue mulching @3 t ha^{-1}, RM6: residue mulching @5 t ha^{-1}, N75 and N100: 75% and 100% N application to preceding rice crop.

Table 9
Carbon footprint of a 3-yr conservation agriculture experiment of rice maize cropping system influenced by tillage, residue mulch and N application.

			Carbon footprint (CO_2-e kg ha^{-1})							CFy (CO_2-e kg Mg^{-1})
			Diesel	Fertilizer	Seed	Pesticides	Labour	N_2O emission	Total	
ZT	WR	$N_{75\%}$	116	830	92	65	190	183	1475	127
		$N_{100\%}$	123	948	92	65	190	207	1624	138
	RM_3	$N_{75\%}$	133	830	92	66	198	261	1579	133
		$N_{100\%}$	133	948	92	66	199	299	1736	143
	RM_6	$N_{75\%}$	136	830	92	70	190	347	1663	137
		$N_{100\%}$	136	948	92	70	199	372	1815	147
CT	WR	$N_{75\%}$	491	830	92	29	225	237	1904	151
		$N_{100\%}$	491	948	92	29	225	268	2053	160
	RM_3	$N_{75\%}$	511	830	92	32	213	330	2007	146
		$N_{100\%}$	515	948	92	32	213	342	2141	152
	RM_6	$N_{75\%}$	521	830	92	34	209	403	2089	154
		$N_{100\%}$	521	948	92	34	209	428	2232	161

ZT, Zero tillage; CT, Conventional tillage; WR, Without residues; RM3, Residue mulching at the rate of 3 tonnes per hectare; RM6, Residue mulching at the rate of 6 tonnes per hectare.

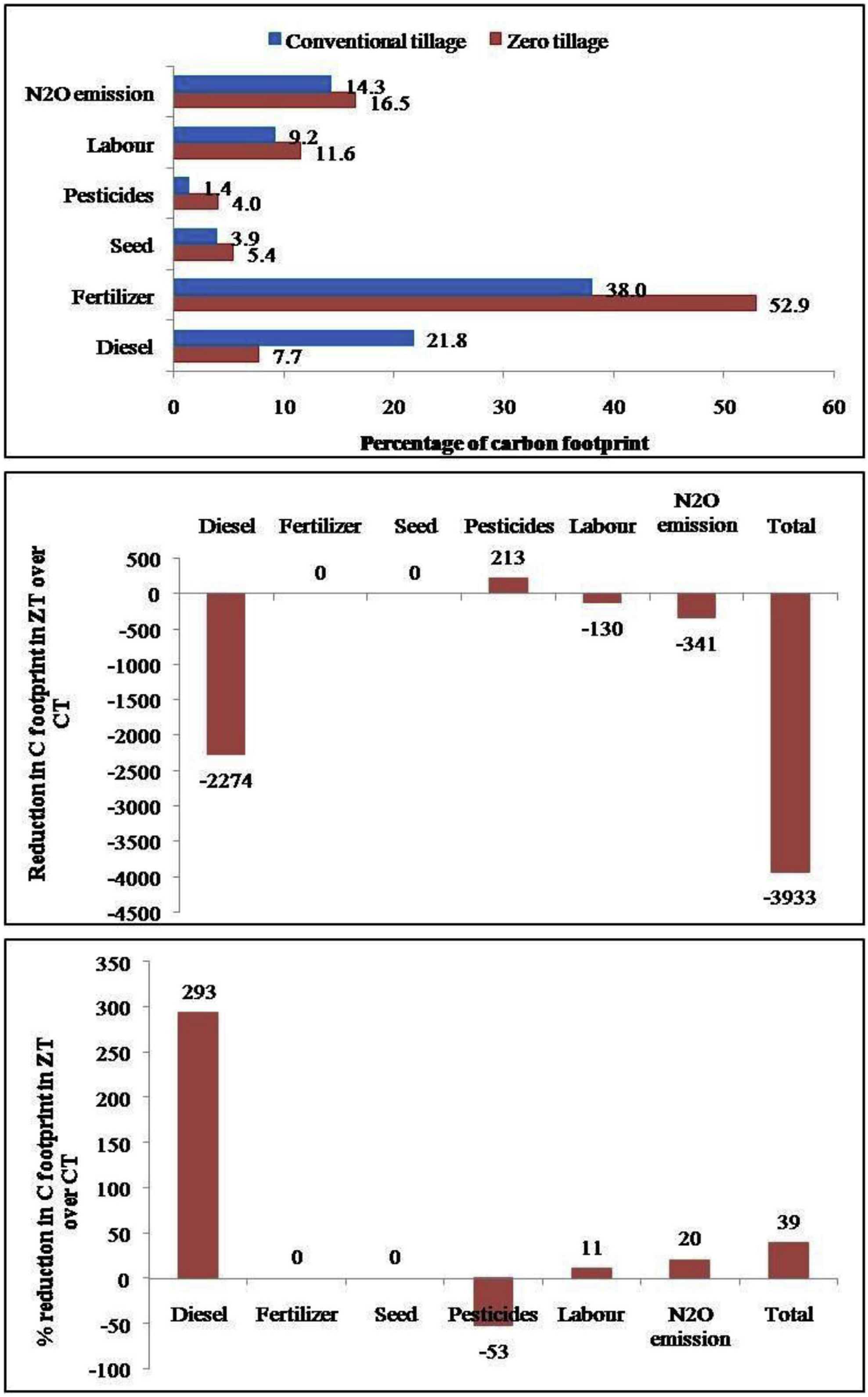

Fig. 4. Carbon footprint pattern and comparison in reduction in carbon footprint under zero and conventional tillage influenced by residue mulch and N application.

insight into the effects of various conservation practices on maize yield, carbon and energy budgeting, soil properties and N_2O emission in Eastern states of India. Firstly, it was found that zero-tillage significantly improved the soil properties but with the yield penalty of around 10–15% over the CT. A 30% decrease in maize yield in ZT over CT in China was also reported by Chen et al. (2011). System productivity was highest under CT which ultimately led to higher energy and carbon consumption and output energy

Table 10
Carbon input, output and efficiency of a 3-yr conservation agriculture experiment of rice maize cropping system influenced by tillage, residue mulch and N application.

			Carbon input (kg ha^{-1})	Carbon output (kg ha^{-1})	Carbon efficiency	Carbon sustainability index
ZT	WR	$N_{75\%}$	584	5324	9.11	8.11
		$N_{100\%}$	622	5412	8.71	7.71
	RM_3	$N_{75\%}$	596	5650	9.47	8.47
		$N_{100\%}$	626	5733	9.16	8.16
	RM_6	$N_{75\%}$	603	5421	8.98	7.98
		$N_{100\%}$	633	5526	8.73	7.73
CT	WR	$N_{75\%}$	703	5817	8.28	7.28
		$N_{100\%}$	732	5914	8.08	7.08
	RM_3	$N_{75\%}$	721	6314	8.76	7.76
		$N_{100\%}$	751	6490	8.64	7.64
	RM_6	$N_{75\%}$	732	6248	8.53	7.53
		$N_{100\%}$	762	6376	8.37	7.37
$LSD_{P=0.05}$			–	92.1	0.24	0.24

ZT, Zero tillage; CT, Conventional tillage; WR, Without residues; RM3, Residue mulching at the rate of 3 tonnes per hectare; RM6, Residue mulching at the rate of 6 tonnes per hectare.

Table 11
Soil chemical properties in a 3-yr conservation agriculture experiment of rice maize cropping system. P values are indicated for analysis of variance of tillage, residue, N application and tillage, residue mulch and N application.

	pH	EC (d S m^{-1})	Available nutrients (Kg ha^{-1})		
			N	P	K
Tillage systems (T)					
ZT	5.72	0.067	204.7	28.1	226.7
CT	5.75	0.070	179.4	24.0	195.4
$LSD_{P=0.05}$	ns	ns	16.41	3.21	9.51
Residue Incorporation(R)					
WR	5.71	0.069	161.2	20.4	177.9
RM3	5.84	0.071	196.1	26.7	212.1
RM6	5.67	0.066	218.7	30.9	243.0
$LSD_{P=0.05}$	ns	ns	23.82	3.45	25.11
Nitrogen Application (N)					
$N_{75\%}$	5.76	0.066	186.6	25.2	202.8
$N_{100\%}$	5.72	0.072	197.4	26.8	219.3
$LSD_{P=0.05}$	ns	ns	9.83	1.35	11.34
TxR $LSD_{P=0.05}$	ns	ns	41.25	5.97	43.5
TxN $LSD_{P=0.05}$	ns	ns	13.90	1.90	16.04
RxN $LSD_{P=0.05}$	ns	ns	17.02	2.33	19.64
TxRxN $LSD_{P=0.05}$	ns	ns	24.07	3.29	27.78

ZT, Zero tillage; CT, Conventional tillage; WR, Without residues; RM3, Residue mulching at the rate of 3 tonnes per hectare; RM6, Residue mulching at the rate of 6 tonnes per hectare.

but overall efficiency of energy use and carbon foot prints was lower as compared to ZT. Among the tillage systems, ZT saved considerable energy over CT, especially in machinery and diesel use leading to around 56% total energy saving. The reduction in input energy under ZT is due to the exclusion of unnecessary tillage operations, minimum intercultural operations and manual weeding which consumed the major part of energy (Pratibha et al., 2015) after fertilizer application.

In a study of rice cultivation under minimum tillage, Nunes et al. (2016) reported that following conservation tillage reduce the GHG emission by 61%. Results of this study indicated that the daily and annual N_2O flux was significantly higher from CT (20.4%) than ZT soil. The effects of crops in rotation on N_2O emissions after adopting ZT may be governed by the quality and quantity of aboveground crop residues and roots in soil profile. Variation in crop rotation and crop diversification can produce more residues and roots, but most of the crops in the rotation were cereals crops (such as maize, wheat, and barley) with high C:N ratio. The decomposition of crop residues with high C: N ratio could stimulated microbial N immobilization in soil, thus reduce the available N for N_2O production (Chen et al., 2013), this might be the reason for reduction in N_2O emission under ZT. Residue mulching significantly increased the annual N_2O flux, around 64.6 and 48.2% higher N_2O released from soil when mulching was done with residue as compared to no residue application. Crop straw has direct and indirect positive

Table 12
Soil carbon fractions in a 3-yr conservation agriculture experiment of rice maize cropping system. P values are indicated for analysis of variance of tillage, residue, N application and tillage, residue mulch and N application.

	TOC (%)	POSC (μg g^{-1})	WSC (μg g^{-1})	RMC (μg Cg^{-1})	MBC (μg Cg^{-1})
Tillage systems (T)					
ZT	0.63	705.8	124.1	127.4	194.2
CT	0.58	673.0	108.9	115.2	169.4
$LSD_{P=0.05}$	0.03	35.24	17.77	4.39	11.37
Residue Incorporation(R)					
WR	0.55	609.5	97.7	96.2	149.0
RM3	0.61	703.3	116.7	123.2	178.7
RM6	0.65	755.4	135.0	144.4	217.1
$LSD_{P=0.05}$	0.05	20.39	18.22	15.34	22.65
Nitrogen Application (N)					
$N_{75\%}$	0.59	682.2	111.2	119.6	173.2
$N_{100\%}$	0.62	696.6	121.8	122.9	190.4
$LSD_{P=0.05}$	0.02	8.75	7.85	9.68	11.78
TxR $LSD_{P=0.05}$	0.088	35.32	31.55	26.57	39.23
TxN $LSD_{P=0.05}$	0.027	12.37	11.10	13.68	16.66
RxN $LSD_{P=0.05}$	0.030	15.15	13.60	16.76	20.40
TxRxN $LSD_{P=0.05}$	0.048	21.42	19.24	23.7	28.85

ZT, Zero tillage; CT, Conventional tillage; WR, Without residues; RM3, Residue mulching at the rate of 3 tonnes per hectare; RM6, Residue mulching at the rate of 6 tonnes per hectare; TOC, Total organic carbon; POSC, Permanganate oxidizable carbon; WSC, Water soluble carbon; RMC, Readily mineralizable carbon; MBC, Microbial biomass carbon.

Table 13
Soil microbial properties in a 3-yr conservation agriculture experiment of rice maize cropping system. P values are indicated for analysis of variance of tillage, residue, N application and tillage, residue mulch and N application.

	Bacteria (10^5)	Fungi (10^4)	Actino-mycetes (10^5)	Denitrifier (10^5)	Ammonium Oxidizer (10^5)	Nitrate Oxidizer (10^5)
Tillage systems (T)						
ZT	12.95	1.80	3.56	6.22	2.32	4.89
CT	10.67	1.19	2.79	5.07	1.78	4.25
$LSD_{P=0.05}$	0.87	0.38	0.39	0.79	0.06	0.24
Residue Incorporation(R)						
WR	7.73	0.98	2.52	4.78	1.49	3.79
RM3	12.31	1.36	3.08	5.56	2.10	4.46
RM6	15.39	2.15	3.94	6.58	2.55	5.46
$LSD_{P=0.05}$	1.59	0.35	0.28	1.19	0.22	0.41
Nitrogen Application (N)						
$N_{75\%}$	11.36	1.38	3.03	5.45	1.92	4.39
$N_{100\%}$	12.26	1.62	3.33	5.83	2.17	4.75
$LSD_{P=0.05}$	0.57	0.11	0.13	0.41	0.11	0.12
TxR $LSD_{P=0.05}$	1.75	0.605	0.486	2.06	0.375	0.708
TxN $LSD_{P=0.05}$	0.80	0.149	0.186	0.576	0.152	0.172
RxN $LSD_{P=0.05}$	0.98	0.182	0.228	0.705	0.187	0.211
TxRxN $LSD_{P=0.05}$	1.38	0.258	0.323	0.998	0.264	0.298

ZT, Zero tillage; CT, Conventional tillage; WR, Without residues; RM3, Residue mulching at the rate of 3 tonnes per hectare; RM6, Residue mulching at the rate of 6 tonnes per hectare.

Table 14
Soil enzymatic activities in a 3-yr conservation agriculture experiment of rice maize cropping system. P values are indicated for analysis of variance of tillage, residue, N application and tillage, residue mulch and N application.

	Acid Phosphatase (μg g^{-1} soil hr^{-1})	Alkaline Phosphatase (μg g^{-1} soil hr^{-1})	DHA (μg TPF g $^{-1}$ d $^{-1}$)	FDA (μg of fluroscein g-1 soil h^{-1})	Urease (μg g^{-1} soil)	β-glucosidase (μg p-nitrophenol g^{-1} d^{-1})	MBN (μg N g^{-1} of soil)
Tillage systems (T)							
ZT	89.6	63.1	83.3	4.47	310.0	50.0	0.0193
CT	82.0	57.9	62.8	4.14	288.7	41.9	0.0172
$LSD_{P=0.05}$	7.12	8.01	12.26	0.09	13.71	6.96	ns
Residue Incorporation(R)							
WR	79.4	55.5	53.4	3.58	263.4	39.0	0.0153
RM3	85.8	60.6	73.7	4.42	296.3	44.6	0.0184
RM6	92.1	65.4	91.9	4.92	338.4	54.2	0.0210
$LSD_{P=0.05}$	6.17	4.43	9.71	0.24	13.86	5.56	ns
Nitrogen Application (N)							
$N_{75\%}$	85.0	59.6	71.1	4.26	296.6	44.7	0.0176
$N_{100\%}$	86.5	61.4	75.0	4.35	302.2	47.1	0.0189
$LSD_{P=0.05}$	ns	ns	ns	ns	5.63	ns	ns
TxR $LSD_{P=0.05}$	14.51	7.68	16.81	0.408	23.99	9.63	ns
TxN $LSD_{P=0.05}$	4.49	2.78	6.92	0.13	7.96	2.47	ns
RxN $LSD_{P=0.05}$	5.51	3.40	8.48	0.16	9.75	3.02	ns
TxRxN $LSD_{P=0.05}$	7.79	4.81	ns	0.238	13.79	4.28	ns

ZT, Zero tillage; CT, Conventional tillage; WR, Without residues; RM3, Residue mulching at the rate of 3 tonnes per hectare; RM6, Residue mulching at the rate of 6 tonnes per hectare.

effects on N_2O production. The decomposition of crop straw directly provided substrate C and N for nitrifiers and denitrifiers, which may stimulate the N_2O production in soil (Chen et al., 2013). Generally, the returned crop straw was commonly mulched on the soil surface in the ZT field, which could reduce soil water evaporation and conserve rainwater in situ, resulting in enhanced soil moisture (Sharma and Acharya, 2000). High soil moisture promotes N_2O production by reducing gas diffusion, therefore, crop straw return may weaken the effects of ZT on the mitigation of N_2O and CH_4 emissions (Feng et al., 2018). Application of higher N resulted in 6.4% annual N_2O release in CT and 11.4% in ZT. Regina and Alakukku (2010) reported the lower N_2O fluxes from the ZT treatments; this may be a result of the higher bulk density which may limit the gas diffusion from soil to the environment (Ball et al., 1999). According to Grant et al. (2004), adoption of ZT on larger scale resulted in reduction of N_2O emission by 17–33% in Canada, due to less decomposition of SOM under ZT. In contradiction to results of this study, Ball et al. (1999) and Oorts et al. (2007) observed that the N_2O fluxes were higher in the ZT treatment. Carbon footprints recorded higher under CT in all the inputs except pesticides, which was higher in ZT. Among various inputs included in the cultivation, CFs were highest for fertilizer application followed by N_2O emission from farm under ZT and diesel in CT. Following of ZT reduced the CFs by about 293 and 11% in diesel and labour, respectively, leading to 39% total reduction as compared to CT. Apart from tillage methods, residue mulching and higher N application to rice also increased CO_2-e emissions, in totality RM6 and RM3 led to 10.5 and 5.8% greater CFs as compared to WR. Global warming potential and CO_2-e emissions was increased with reside mulching as compared to no mulching and further an increase was observed with the

higher quantity of residue (Yadav et al., 2018). By adopting ZT carbon input was reduced so as output, but carbon efficiency and sustainability was increased by 6.9 and 7.9% respectively. Carbon budgeting was varied differently with residue mulching, that is low quantity of residue (RM3) increased the carbon efficiency and sustainability upto 5.5 and 6.2% but higher quantity of residue (RM6) did not further increased the efficiency and decreased the sustainability.

4.2. Impact of tillage and residue mulch on soil fertility and health

To combat soil degradation and for soil resilience, conservation agriculture comprising of straw return as mulching, is an important strategy (He et al., 2015). Such tactics is useful for improving soil physic-chemical and biological properties leading to better soil fertility, which resulted in higher nutrient utilization efficiency as well as enhancing the crop productivity (Chen et al., 2015). However, inappropriate methods of straw incorporation could deteriorate soil structure and unbalance nutrients distribution (Kong, 2014), which could limit the crop growth; therefore, optimizing the method of straw retention in conservation tillage is essential for maize production. It suggested by Vanlauwe et al. (2011) that following the long-term inappropriate tillage can damage the physical, biological, or chemical health of soil, referred to as “poor, less-responsive soils”. In this study it was further reported that soil fertility status was improved under ZT by increasing NPK content >15% as compared to CT, apart from that residue mulching resulted in carbon sequestration leading to improvement in soil health index. Annual zero-tillage, involving practice of no-till system yearly over a long period of time, is beneficial for maintenance and enhancement of overall soil health mainly soil structure and biochemical properties of the soil especially the SOC content (Deng et al., 2015) and soil organic matter (Dıaz-Zorita and Grove, 2002). Less tillage operation could reduce the disturbance to methanotrophic microbes (Tellez-Rio et al., 2015) and could also prevent soil aggregates and inhibit organic N mineralization, which is beneficial to the mitigation of N_2O production (Chen et al., 2013). According to Bronick and Lal (2005) tillage disperses the soil particles which damages the soil aggregation and redistributes the MBC in soil, and mineralizes different nutrients but Bayer and Bertol (1999) reported reduction in soil carbon fractions. Zero tillage improved the physio-chemical properties of upper soil layer (0–15 cm) (Lal, 1997) and carbon input can also be enhanced in soil (Chen et al., 2009). During et al. (2002) observed that with ZT and plant residues retained on the surface of soil increase the organic matter in the top soil resulting in increasing soil carbon fractions. Frequent ploughings under CT leads to higher mineralization of nutrients and/or leaching resulted in decrement of organic carbon and nitrogen ultimately poor soil health. Tillage hastens the labile natural C mineralization and SOC debasement, consequently expanding the loss of replaceable natural carbon (Chen et al., 2009). Feng et al. (2003) also reported that soil organic carbon content was more than twice in the top soil layer of the ZT, compared to the CT treatment. The activity of soil microbes can be hasten by the WSC (Flessa et al., 2000) although it is a small portion of total soil carbon but influenced by tillage performed (McGill et al., 1986). According to Leinweber et al. (2001) WSC values were higher in ZT system than in conventionally tilled soil. According to Sandeep et al. (2016) crop residues were more effective in increasing PSOC content of soil in maize–wheat system especially along with full dose mineral N. Labile pools of soil carbon served as the energy source for microbes and determined the activity of soil microflora (Janzen et al., 1998). Soil covering through residue mulching enhances microbial processes (Kandeler et al., 1999) and soil enzymes activities. According to Roldan et al. (2005) higher dehydrogenase and urease activities which indicated the higher biological activity was reported in ZT soils as compared to conventionally tilled soils.

Microbial biomass could also a helpful indicator of tillage-generated changes (Alvarez and Alvarez, 2000) and placement of crop residues may also affect the distribution of MBC. Doran (1987) and Alvarez et al. (1995) found that in ZT ploughed soils microbial biomass was considerably higher even sometimes > 50% over traditional tillage systems. Positive effect of ZT on MBC, MBN and other nutrient availability under zero tilled systems may be due to the fact that it provides a more favorable habitat for microorganisms (Balota et al., 2004). “Rhizosphere effect” may be one of the benefits derived from ZT, which led to significantly higher soil enzymatic activity than CT (Balota et al., 2004), because the organic fraction of soil carbon, microbial C an N and soil enzymes are highly correlated, and affecting the activity to each other. Straw return increased the activities of soil microorganism and enzyme, which significantly promoted the availability of soil N (Xu et al., 2010). Chen et al. (2017) reported that residue application in the soil increased the activity levels of soil enzymes. It indicated that the carbon input via straw return enhanced soil carbon and nitrogen pools, improved soil biological fertility (Zhao et al., 2016), and promoted mineralization of organic material and availability of soil nutrient (Wei et al., 2015), which is beneficial to the nutrient absorption of crop. Results of this study also supported the above statement; the significant positive correlation of carbon fractions, MBC, MBN and soil enzymes was observed (Table 15). Total microbial activity, i.e. active microflora providing extracellular enzymes which was determined as FDA (Adam and Duncan, 2001) like Urease. Dehydrogenase activity was very suitable for an assessment of cropping effects on soil microflora under oxidative environment (Beyer et al., 1993). Eivazi et al. (2003) announced that amendment in the enzyme dynamics of the soil profiles of tilled and no-tilled might be a result of the distinctive varieties in the populaces of oxygen consuming and facultative anaerobic organisms. These changes may be due to the fact that residue and roots of previous crops in the surface soil of ZT can affect microbial activity, also zero tilled soils are less oxidative in nature than those of soils under CT. Long-term adoption of ZT can improve soil structure and inhibition of N_2O emission (Ussiri et al., 2009).

5. Conclusions

For cleaner production technology, reduction in carbon foot prints, energy consumption, gas emission and maintaining soil health simultaneously are the major targets to fulfill the sustainable production aspects of agriculture. It can be concluded that tillage plays an important role in the alteration of soil structure which is a crucial factor for energy, carbon budgeting and N_2O release. Our study concluded that replacing the conventional tillage with zero tillage and soil surface covers with residue mulch decreased the energy inputs, nitrous oxide emission, carbon foot prints, and improved the soil quality, fertility and microbial health. Use of zero tillage has become an effective strategy to increase carbon and its fraction, soil microbiota and improved its enzymatic activities, as these parameters are correlated with each other, improvement in carbon fractions lead to higher yield and low N_2O emission, C and energy inputs. However, soil covering with plant residues enhances the N_2O emission but improved the yield, energy output and carbon efficiency. Approbation of residue mulch based ZT system can save energy in terms of diesel, labour, reduce carbon foot prints but enhance the net farm income, soil health and environment quality leading to food security of the studied cropping system along with similar systems of globe. The study opens up the new opportunities for analyzing GHGs emission and crop yield in non-maize growing seasons. More studies should be conducted to investigate year-

Table 15
Correlation coefficients between soil carbon pool, soil enzymatic activities, system productivity and N_2O emission after 3-yr conservation agriculture experiment of rice maize cropping system.

	TOC	WSC	PSOC	MBC	MBN	DHA	FDA	Urease	Phosp.	Yield	N_2O
TOC	1	0.941	0.916	0.703	0.807	0.800	0.827	0.828	0.856	0.093	0.586
WSC		1	0.903	0.871	0.874	0.926	0.903	0.927	0.958	0.032	0.582
PSOC			1	0.796	0.820	0.875	0.946	0.922	0.874	0.323	0.777
MBC				1	0.760	0.945	0.898	0.936	0.932	0.127	0.634
MBN					1	0.868	0.879	0.826	0.889	−0.076	0.451
DHA						1	0.944	0.956	0.984	−0.003	0.557
FDA							1	0.978	0.931	0.258	0.755
Urease								1	0.949	0.216	0.732
Phosp.									1	−0.045	0.538
Yield										1	0.813
N_2O											1

round N_2O emissions, additionally; this study only evaluated direct N_2O emissions from soil during maize growing seasons. In the future, indirect N_2O emissions and carbon cost should be considered in the assessment of the mitigation potential of crop production and life-cycle assessment of cropping practices could provide more precise references for the recommendation of management practices.

Note

Confirmed that there is no conflict of interest by authors.

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Appendix 1. Detailed methodology of different analysis

Nitrous oxide flux measurement

Nitrous oxide (N_2O) flux from the rice field plots were monitored throughout the year by using the manual closed chamber method. The gas samplings were done after 10 days of sowing the maize crop at 7 days intervals in the dry season. For measuring N_2O flux sampling was done from all the treatments in each replication in the morning around 09:00–09:30 a.m. and in the afternoon at 3.00–3.30 p.m., and the average of both the fluxes was used as estimation of flux for the day (Datta et al., 2009). For measuring N_2O emissions, fabricated Perspex chamber (53 cm length x 37 cm width x 51 cm height) were placed between two rows of maize. To mix the air inside the chamber and draw the air samples into Tedlar gas sampling bags (M/s Aerovironment Inc.) an air circulation pump with an air displacement of 1.5 L min^{-1} (M/s Aerovironment Inc., Monrovia, CA, USA) was connected to polyethylene tubing inside the chamber. Nitrous oxide concentration in the air samples collected in the Tedlar sampling bags were analyzed in a Chemito 2000 gas chromatograph (M/s Thermo Scientific) equipped with an electron capture detector (ECD) and a Porapak Q column (6 feet long, 1/8 in. outer diameter, 80/100 mesh, stainless steel column). The temperature of injector, column and detector were maintained at 200, 60 and 340 °C, respectively, and the carrier gas (N_2) flow was maintained at 15 ml min^{-1}. Before and after each set of measurements the gas chromatograph was calibrated by using 110 parts per billion (ppb) N_2O in N_2 as the primary standard and 310 and 398 ppb N_2O in N_2 as the secondary standard. It was assumed that the emissions followed a linear trend during the periods when no sampling was done, therefore, flux of N_2O was computed by successive linear interpolation of the average emissions on the sampling days (Datta et al., 2009). Cumulative N_2O emissions for the entire cropping period were calculated by plotting the flux values against the days of sampling and were expressed as kg ha^{-1}.

Soil sampling

Soil samples were collected with a sample probe (at the depth of 0–15 and 15–30 cm, three replications per treatment). After mixing the subsamples, a composite soil samples were prepared for the analysis. The fresh soil samples were kept in refrigerator at 4 °C for microbial population and soil enzymatic analysis. The collected soil samples were air-dried for 7 days then sieved through a 2-mm mesh, and stored in plastic jars for analyses of available N, P, K and soil C fractions.

Soil chemical analysis

Alkaline $KMnO_4$ method was used for the determination of available N (Subbiah and Asija, 1956) and Bray's extractant method of Dickman and Bray (1940) and ammonium acetate extractant method of Hanway and Heidel (1952) was used for the estimation of available phosphorus and potassium, respectively. Microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) of soil was determined by modified chloroform fumigation–extraction method of Witt et al. (2000) and Brookes et al. (1985), respectively. Readily mineralizable carbon (RMC) content of the soil was measured by following the procedure of Inubushi et al. (1991), extraction was done with 0.5 M K_2SO_4 followed by wet digestion with dichromate (Vance et al., 1987). For estimation of water soluble carbohydrate carbon (WSC) and permanganate oxidizable carbon (PSOC) procedure of Haynes and Swift (1990) and Blair et al. (1995) was followed, respectively.

Soil enzymatic activities and microbial populations

The procedure of Adam and Duncan (2001) was used for determining the Fluorescein diacetate (FDA) hydrolysis activity. Dehydrogenase activity (DHA) was estimated by the reduction of 2,3,5-triphenyltetrazolium chloride (TTC) (Casida et al., 1964). The β-glucosidase (BGLU) and Urease activity was assayed following the procedure of Eivazi and Tabatabai (1988) and Tabatabai and Bremner (1972), respectively. For measuring the activities of acid and alkaline phosphatase activity, procedure of Tabatabai and Bremner (1969) was followed in which p-nitrophenyl phosphate disodium (pNPP, 0.15 M) was used as substrate and pH of 0.5 M sodium acetate was maintained at 6.5 and 11 for determining acid and alkaline phosphatase activity, respectively. Spread plate

technique was used for estimation of total bacterial, fungal and actinomycetes populations. Culturable NH_4^+ and NO_2^- oxidizing atutotrophs (AMOOX and NITROX, respectively) were enumerated by the MPN method (Schmidt and Belser, 1982). Populations of denitrifying bacteria were estimated by following the method of Abd-el-Malek et al., (1974).

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